10. Growth of the Landfill Gas Industry

This chapter discusses the development of the landfill gas industry and assesses its prospects for expansion. It describes the regulations that affect the landfill gas industry; provides information on U.S. Environmental Protection Agency (EPA) efforts to encourage the conversion of landfill gas (LFG) emissions into energy; provides information on the economics of LFG conversion into energy; and provides information on the impact of new environmental regulations.

Municipal Solid Waste Landfills, Landfill Gas, and Control Systems

Each person in the United States generates about 4.5 pounds of waste per day, or almost 1 ton per year, most of which is deposited in municipal solid waste (MSW) landfills.[167] As MSW decomposes, it produces a blend of several gases, including methane (about 50 percent). Table 28 shows the main constituents of LFG and their proportions. Methane (CH_4) is a greenhouse gas and also poses explosion hazards if uncontrolled. On the other hand, it is the main component of natural gas and can be a valuable source of energy. Other LFG constituents, such as nonmethane organic compounds (NMOCs), can contribute to the formation of smog. Others pose health hazards due to their toxicity.

Gas collection systems operate continuously. They usually consist of vertical wells and sometimes horizontal trenches or other zones filled with permeable material within the waste, from which LFG is extracted by application of a vacuum. Once the gas is withdrawn, it can be flared[168] or processed.

Development of the Landfill Gas Industry

The first commercial gas energy recovery project was at the Palos Verdes Landfill, in Rolling Hills, California, in 1975.[169] The project converted LFG to pipeline-quality gas that was sold to the Southern California Gas Company. Several other projects to convert LFG to pipeline-quality gas were started in the late 1970s in California, including Mountain View in 1978 and Monterey Park in 1979. The first direct heating boiler projects were brought on line in the late 1970s and early 1980s. The first electricity generation projects took place at Brattleboro, Vermont, in 1982. Most projects are located in California and the Northeast.

LFG Utilization Applications

There are five main ways to recover energy from LFG: direct heating, electricity generation, chemical feedstock, purification to pipeline-quality gas, and heat recovery. Each of these methods has a variety of LFG applications. A complete list of applications and technologies is provided below.

1. Direct Heating Applications:
   - Use for industrial boilers
   - Space heating and cooling
   - Industrial heating/cofiring.
2. Electricity Generation Applications:
   - Processing and use in reciprocating internal combustion (RIC) engines (i.e., stoichiometric combustion or lean combustion)
   - Processing and use in gas and steam turbines
   - Processing and use in fuel cells.
3. Feedstock in Chemical Manufacturing Processes:
   - Conversion to methanol (and optional subsequent industrial or vehicular fuel use)
   - Conversion to diesel fuel (and subsequent use as vehicular fuel).
4. Purification to Pipeline-Quality Gas:
   - Utilization as vehicular fuel
   - Incorporation into local natural gas network.
5. Heat-Recovery from Landfill Flares:
   - Using organic Rankine cycle
   - Using Stirling cycle engines.

[167]U.S. Environmental Protection Agency, *Landfill Methane Outreach Program*, EPA-430-F-95-068A (Washington, DC, April 1995).

[168]"Flaring" is combustion of gas to avoid unsafe accumulation.

[169]Most of the information in this section was obtained from M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*, EPA-600/R-95-035, prepared by E.H. Pechan and Associates, Inc., for the Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency (Washington, DC, March 1995).

Table 28. Landfill Gas (LFG) Constituent Gases

Constituent Gas	Concentration in LFG	
	Range	Average
Methane (CH_4)	35 to 60 percent	50 percent
Carbon Dioxide (CO_2)	35 to 55 percent	45 percent
Nitrogen (N_2)	0 to 20 percent	5 percent
Oxygen (O_2)	0 to 2.5 percent	<1 percent
Hydrogen Sulfide (H_2S)	1 to 1,700 ppmv	21 ppmv
Halides	NA	132 ppmv
Water Vapor (H_2O)	1 to 10 percent	NA
Nonmethane Organic Compounds (NMOCs)	237 to 14,294 ppmv	2,700 ppmv

NA = not available. ppmv = parts per million by volume.

Note: Highest values occur in perimeter wells.

Sources: G.J. Sandelli, *Demonstration of Fuel Cells To Recover Energy from Landfill Gas. Phase I Final Report: Conceptual Study,* EPA-600-R-92-007, prepared for the U.S. Environmental Protection Agency by International Fuel Cells Corporation (Washington, DC, January 1992); M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*, EPA-600/R-95-035, prepared for the Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency by E.H. Pechan and Associates, Inc. (Washington, DC, March 1995).

Recent Regulatory History

This section reviews the most recent regulations that affect the LFG industry. Table 29 summarizes the regulations discussed in this section.

Resource Conservation and Recovery Act (RCRA), Subtitle D

National Municipal Solid Waste Landfill Criteria

The original regulations under Subtitle D of the Resource Conservation and Recovery Act of 1976 (RCRA), issued by EPA's Office of Solid Waste, covered the migration (via underground routes) and collection of explosive mixtures in buildings. A more stringent set of Subtitle D regulations was promulgated in the *Federal Register* on October 9, 1991.[170] On that date, new standards were issued for all new MSW landfills that were receiving waste 2 years after the rule's publication in the *Federal Register*.[171,172] Although the rule establishes minimum health and environmental protection standards, implementation of the regulations is left largely to the State governments.[173] The regulations are intended as minimal national criteria to guide States in establishing and enforcing their own regulations, which must be reviewed and approved by the EPA.[174]

Specific applicability criteria are as follows:

1. All new MSW landfills that were receiving waste 2 years after October 9, 1991, must comply fully with the RCRA.
2. For landfills that stopped taking in waste between October 9, 1991, and October 9, 1993, only compliance with final cover requirements is necessary.
3. The standards do not apply to landfills that stopped operating prior to October 9, 1991.

The regulations established comprehensive protective standards in six categories of MSW landfill management:

1. Location restrictions
2. Operating requirements
3. Design standards
4. Groundwater monitoring and corrective action
5. Closure and postclosure care
6. Financial assurance.

[170]R. Woods, "Building a Better Liner System," *Waste Age* (March 1992), p. 26.

[171]In July 1993, the EPA provided some extensions to the effective date of the standards for existing, smaller landfills. In addition, financial assurance and closure requirements for all existing landfills were delayed for 1 year.

[172]S.M. Roe, P.G. Fields, and R.E. Coad, *Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization*, EPA-600/R-95-089, prepared by E.H. Pechan & Associates, Inc., for the U.S. Environmental Protection Agency (Washington, DC, July 1995).

[173]U.S. Environmental Protection Agency, *Criteria for Solid Waste Disposal Facilities: A Guide for Owners/Operators*, EPA/530-SW-91-089 (Washington, DC, March 1993).

[174]U.S. Environmental Protection Agency, *Safer Disposal for Solid Waste: The Federal Regulations for Landfills*, EPA/530-SW-91-092 (Washington, DC, March 1993).

Table 29. Regulatory Milestones Affecting the Landfill Gas Industry, 1976-1996

Agency, Date	Milestone/Regulation	Effect
EPA, 1976	Original regulations under Subtitle D, Resource Conservation and Recovery Act (RCRA)	Restrict the migration and require collection of explosive mixtures. The measure increased the safety of landfills (danger of explosion, health hazards, etc.).
FERC, 1978	Public Utility Regulatory Policies Act of 1978 (PURPA)	Requires utilities to interconnect with small power producers (SPP), including LFG energy recovery projects, and purchase the energy at the utilities' avoided costs.
EPA, 1988	Proposed new landfill regulations under Subtitle D, RCRA	See below.
EPA, 1991	Promulgation of new landfill regulations under Subtitle D, RCRA, setting standards in six categories: location restrictions, operating requirements, design standards, groundwater monitoring and corrective action, closure and postclosure care, and financial assurance	Depending on timing of implementation (see below). Once implemented: strengthen existing regulations; increase safety and reduce environmental impact; and, indirectly, increase costs of compliance for landfill operators.
EPA, 1991	Proposed New Source Performance Standards (NSPS) under Section 111(b) and Emissions Guidelines under Section 111(d) of the Clean Air Act (CAA)	The NSPS for MSW landfills designate LFG emissions as a pollutant. The proposed emissions guidelines call for control of LFG emissions through installation and maintenance of LFG control systems at MSW landfills with capacity in excess of 167,000 tons. The EPA estimated in 1992 that 621 landfills would be required to install collection/control systems when the regulations were implemented.
EPA, 1993	One- and two-year extensions of some effective dates in Federal landfill regulations under Subtitle D, RCRA	Implementation schedule delay; allowed more time for small and other special case landfills to either comply with regulations for operating landfills or shut down.
EPA, 1994-1995	Effective dates for most regulations under Subtitle D, RCRA	The operations and closure/postclosure criteria require monitoring and control measures to prevent soil concentrations of methane higher than 5 percent at the site boundary, monitoring of hazardous waste, and monitoring of LFG levels for 30 years after closure. Encourages use of LFG collection systems as a form of control. As part of hazardous waste monitoring, requires disposal of LFG condensate accumulated during control and energy recovery processes following either RCRA regulations (safe disposal at a Subtitle C facility) or the Clean Water Act (treatment and sewage disposal). Depending on choice, costs range from $0.70 to $1.50 per gallon. Because less condensate is created if LFG is flared, disposal costs are about five times higher in energy recovery projects, thereby discouraging utilization of LFG in favor of flaring.
EPA, 1994-1995	Effective dates for compliance with applicable CAA and Clean Water Act regulations under RCRA	RCRA requires compliance with applicable CAA and Clean Water Act regulations, such as restrictions on primary and byproduct emissions (i.e., NO_X and CO) in ozone nonattainment regions. Encourages the use of LFG control systems, but sometimes discourages the use of energy recovery systems.
EPA, 1994	Proposed revisions to some CAA regulations that apply to new and existing landfills, including renewable energy reserve credits (Title IV of CAA Acid Rain Program) (see below)	Strict LFG toxic and greenhouse constituent gas control through collection systems. Renewable energy reserve credits encourage LFG energy recovery once LFG is collected (see below).

See notes at end of table.

Table 29. Regulatory Milestones Affecting the Landfill Gas Industry, 1976-1996 (Continued)

Agency, Date	Milestone/Regulation	Effect
FERC, 1995	Federal Energy Regulatory Commission (FERC) rejection of the component of California's Biennial Resource Plan Update that restricted bidding for wholesale power to qualifying facilities (QFs)	States may not assign a preference to bidding for energy sources under PURPA. States may not assign externality benefits to particular technologies.
EPA, 1996	Final regulation under the CAA establishing standards for new and guidelines for existing large MSW landfills	Requires landfills that emit LFG in excess of 50 megagrams (Mg) per year to control emissions. New and existing landfills designed to hold at least 2.5 million Mg of MSW are also required to install gas collection systems, unless nonmethane organic compounds (NMOCs) emissions are less than 50 Mg per year. About 280 landfills are affected. Surface methane must be monitored on a quarterly basis. Waste disposal cost increases are estimated by EPA at 20 to 40 cents per household. By requiring more extensive (and expensive) LFG control, the rule may encourage some landfills to explore LFG energy recovery options. However, because the rule increases the costs of both flaring and energy recovery options, most owners/operators will likely continue to choose flaring.

Notes: EPA = U.S. Environmental Protection Agency. FERC = Federal Energy Regulatory Commission.

Source: Science Applications International Corporation, *Renewable Industry and Project Descriptions*, prepared for the Office of Coal, Nuclear, Electric and Alternate Fuels under contract DE-AC01-92EI21944 (McLean, VA, August 1996).

Because of the expenses related to these regulations, operators were required to show that they had financial mechanisms to cover the costs of closure, postclosure care, and any needed cleanups from releases. Some exemptions were granted to certain small landfills serving communities that dispose of less than 20 tons of MSW per day.

Specific Regulations Pertaining to Landfill Gas and Methane Control

Both the operating requirements and the closure and postclosure care requirements included provisions for controlling and monitoring LFG.[175] The box on page 103 shows the regulatory criteria that affect LFG specifically. LFG control and conversion involves the compression of the gas. This compression creates LFG condensate, which is a hazardous waste under RCRA because of its NMOC content. This classification requires disposal either under RCRA or Clean Water Act (CWA) rules. Under RCRA, condensate is treated and safely disposed of at a Subtitle C facility. Under the CWA, it is treated and eliminated through the sewer.[176]

Extension of Some Effective Dates in Federal Landfill Regulations

In July 1993, the EPA proposed the following modifications to the relevant compliance dates of certain provisions of the October 1991 rule:

- Postponement of the effective date for existing, qualifying smaller landfills from October 9, 1993, to April 9, 1994[177]
- Elimination of the exemption from groundwater monitoring requirements, and extension of the effective date of the Federal regulations to October 9, 1995, for landfills that previously qualified for the exemption
- Extensions of 6 months for financial assurance and closure requirements for all existing landfills.

[175]National Renewable Energy Laboratory, *Using Landfill Gas for Energy: Projects that Pay* (Golden, CO, May 1994).

[176]M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*; and T.D. Williams, "Making Landfill Gas an Asset," *Solid Waste & Power* (July / August 1993), p. 22.

[177]RCRA defines a small landfill as one serving a community that disposes of less than 20 tons of MSW per day, averaged yearly. For further information, see U.S. Environmental Protection Agency, *Criteria for Solid Waste Disposal Facilities: A Guide for Owners/Operators*.

MSW Landfill Criteria Provisions Under Subtitle D of RCRA That Affect LFG and Methane Specifically

Two of the six MSW landfill gas criteria under the 1991 Subtitle D of RCRA affect LFG and methane specifically. The two criteria, an abbreviated version of the relevant provisions, and the effect on LFG are as follows:

1. Under operation provisions:
   - Receipt of regulated hazardous waste—The owner/operator must set up a program to detect and prevent disposal of regulated quantities of hazardous wastes and polychlorinated biphenyl (PCB) wastes. This affects disposal of LFG condensate.
   - Cover material—The owner/operator must cover disposed solid waste with at least 6 inches of earthen material at the end of each operating day to control vectors, fires, odors, blowing litter, and scavenging. This inhibits the dispersion of LFG.
   - Explosive gases—The owner/operator must set up a program to check for methane gas emissions at least every 3 months. If the limits specified in the regulations are exceeded, the owner/operator must immediately notify the State/Tribal director and take immediate steps to protect human health and the environment. The owner/operator also must develop and implement a remediation plan within 60 days. This encourages the installation and maintenance of LFG control systems.
   - Air quality—Owners/operators must comply with the applicable requirements of their State Implementation Plans for meeting Federal (CAA) air quality standards. This encourages the installation and maintenance of LFG control systems, but may discourage energy recovery in favor of flaring.
2. Under closure and postclosure care provisions:
   - For 30 years after closure, the owner/operator is responsible for maintaining the integrity of the final cover, monitoring groundwater and methane gas, and continuing leachate management. This encourages the continued operation of LFG control systems after closure.

Source: U.S. Environmental Protection Agency, *Criteria for Solid Waste Disposal Facilities: A Guide for Owners/Operators*, EPA/530-SW-91-089 (Washington, DC, March 1993).

Clean Air Act (CAA) Regulations

New Source Performance Standards and Emissions Guidelines of 1991

In 1991, the EPA's Office of Air Quality Planning Standards designated "municipal solid waste landfill emissions" as a pollutant to be regulated under the Clean Air Act (CAA), Section 111(b) (New Source Performance Standards (NSPS) for new landfills) and Section 111(d) (Emissions Guidelines for existing landfills).[178] The standards limit NMOCs in LFG emissions. NMOCs are of concern because of their interaction with nitrous oxides (NO_x) to form ozone, a primary cause of smog. Although the guidelines did not directly regulate methane (CH_4), they did so indirectly by requiring the installation and maintenance of LFG collection and control systems.

Renewable Energy Reserve Credits

Renewable Energy Reserve credits are available under Title IV of the CAA Acid Rain Program for LFG-to-energy projects. The Renewable Energy Reserve is a special bonus pool of sulfur dioxide (SO_2) allowances set aside to reward new initiatives in renewable technologies. For every 500 megawatthours of electricity generated through landfill energy recovery, a public utility earns one allowance. The current market value for a sulfur dioxide allowance is approximately $100.

New Source Performance Standards and Emissions Guidelines of 1996

In 1994, the EPA's Office of Air Quality Planing Standards proposed new CAA regulations for new and existing MSW landfills. The final regulation was issued on March 1, 1996. It sets revised performance standards for new landfills and emission guidelines for existing ones.[179] The regulations require large landfills that emit LFG in excess of 50 megagrams per year to install and maintain technology to control LFG emissions. New and existing landfills designed to hold at least 2.5 million megagrams of MSW are also required to install gas collection systems, unless NMOC emissions are

[178]S.A. Thorneloe, "Landfill Gas Utilization—Options, Benefits, and Barriers," paper presented at the Second U.S. Conference on Municipal Solid Waste Management (Arlington, VA, June 3-5, 1992).

[179]U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *Fact Sheet* (Washington, DC, March 1, 1996).

lower than 50 megagrams per year. NMOCs include toxics such as benzene, carbon tetrachloride, and chloroform.[180]

The rule provides owners/operators with a tier system for determining whether controls will be required. If initial calculations determine emissions to be above the limit of 50 megagrams per year, the tier system provides the opportunity to conduct sampling and obtain site-specific values to prove that emissions are below the limit and that controls are not required. The rule also contains an operational standard that requires the monitoring of a landfill's surface methane concentration on a quarterly basis. If the concentration is greater than 500 parts-per-million (ppm) after three consecutive measurements, control system expansion is required.

Other Federal and State Environmental Regulations That Affect the LFG Industry

The reach of Federal, State, and local environmental regulations is expanding at an increasing rate. Prospective landfill developers must consult different local and State government agencies to obtain the latest version of their solid waste, air quality, and health regulations. A single project or even a project phase may require obtaining multiple permits from different agencies. For instance, 48 pieces of State legislation affecting solid waste were enacted in California in 1991 alone.[181] As stated earlier, Subtitle D of RCRA sets minimum criteria used by States to establish and enforce their own EPA-approved regulations, which can be more, but not less, strict. A complete list of State regulations affecting landfills would stretch hundreds of pages and is beyond the scope of this report.[182]

Public Utility Regulatory Policies Act of 1978

A provision under the Public Utility Regulatory Policies Act of 1978 (PURPA) requires utilities to interconnect with small power producers, including LFG energy recovery projects, and purchase the energy at the utilities' avoided cost. In 1995, the Federal Energy Regulatory Commission (FERC) rejected the component of California's Biennial Resource Plan Update that restricted bidding for wholesale power to qualifying facilities (QFs), such as renewable energy resources, compared to other small power producers, such as nonrenewable resources. As a result, States may not assign a preference to bidding for LFG-generated energy under PURPA. FERC also rejected preferential treatment via externality adders that would have the effect of setting rates for QFs above avoided cost.

The Economics of LFG Control and Utilization

Advantages of LFG Energy Recovery

The advantages of energy recovery include decreased emissions of methane, NMOCs, and toxics (e.g., benzene, carbon tetrachloride, and chloroform). Although carbon dioxide (CO_2) emissions increase with the energy recovery option, the net atmospheric balance is a positive one because CO_2 emissions are significantly less radiative (i.e., the alleged "greenhouse effect" is less) than methane emissions.

Economics of Converting LFG Into Energy

The average size of an LFG energy recovery project is about 3 megawatts, with typically over 95 percent availability. The number of commercial LFG energy recovery projects has grown from 4 in 1981 to about 130 in 1996.[183] Appendix H shows selected case studies of LFG commercial energy recovery projects. Even though there has been a large increase in projects, EPA estimates that over 700 landfills across the United States could install economically viable landfill gas energy recovery systems, but have not. In addition, about 30 of the original conversion and direct use projects initiated in the 1970s and 1980s have had to shut down due to more competitive market conditions of the 1990s.[184,185,186] Therefore, although the advantages of LFG energy recovery are many, there are few successful commercial projects relative to the number of MSW landfills due to prevailing market conditions and the array of other formidable barriers that confront project developers (see box on page 105).

[180]National Renewable Energy Laboratory, *Using Landfill Gas for Energy: Projects that Pay* (Golden, CO, May 1994).

[181]Solid Waste Association of North America, *List of Solid Waste Legislation Enacted in 1991* (Silver Springs, MD, 1992).

[182]Telephone communication between Science Applications International Corporation (McLean, VA) and the Bureau of National Affairs, Inc. (Washington, DC) (August 28, 1996).

[183]Personal communication between Science Applications International Corporation (McLean, VA) and S.A. Thorneloe, Global Emissions and Control Division, Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency (August 30, 1996).

[184]"Landfill Gas Recovery Projects Reviewed by NREL," *BioCycle*, Vol. 37, No. 2 (February 1996), p. 25.

[185]U.S. Environmental Protection Agency, *Landfill Methane Outreach Program*, EPA-430-F-95-068A (Washington, DC, April 1995).

[186]Personal communication between Science Applications International Corporation (McLean, VA) and Jean Bogner, Argonne National Laboratory (Chicago, IL) (August 28, 1996).

Barriers to Recovery and Conversion

- Low oil and gas prices (current and projected future)
- Need for expensive new, sometimes untested, technology (e.g., fuel cells)
- High transportation costs (e.g., dedicated pipelines have to be built for relatively small supplies of gas)
- High debt-service rates for projects that generate electricity or pipeline-quality gas
- Limited or unstable marketplace
- Obtaining third-party project financing at reasonable cost (financing is difficult, time-consuming, and proportionately more costly for small projects than for large ones)
- Difficulties obtaining air permits, especially for projects located in ozone, nitrogen oxide, and carbon monoxide nonattainment areas, because air boards and utilities often have lengthy permit processes and contract negotiations
- Difficulties in negotiating power contracts with local utilities because they are primarily interested in purchasing low-cost power without considering environmental externalities (e.g., offsets from power plants using fossil fuel)
- Unforeseen costs resulting from compliance with new air quality rules and regulations, and declining energy revenues that cannot be adjusted to offset new costs
- Taxation by some States (e.g., California) on LFG extraction and energy conversion facilities
- Difficulties in complying with overlapping Federal and State energy policies and environmental regulations that may affect these projects.

Source: M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*, EPA-600/R-95-035, prepared by E.H. Pechan and Associates, Inc., for the Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency (Washington, DC, March 1995).

The most significant barrier is low oil and natural gas prices, which make recovery and conversion, with its high initial capital costs, lack of economies of scale, and high transportation costs, uncompetitive in most cases. Table 30 shows a comparison of current costs for the most popular LFG energy recovery technologies. Table 31 shows a comparison of the conditions deemed necessary by industry to achieve cost-competitive LFG control (i.e., flaring) and utilization projects.

Economics of Direct Uses

The most economical options for LFG utilization are direct uses such as process heat and boiler fuel, where the end users are in close proximity (no more than 1 or 2 miles) to the landfill, and whose gas supply needs closely match production at the landfill.[187] In practice, end users are infrequently located near landfills and rarely require continuous fuel in the amounts produced. As of 1992, there were 21 landfills (or less than 20 percent of total energy recovery projects) with direct use of LFG as heating fuel.[188]

Boiler fuel is the most typical direct use and a particularly attractive option since conventional equipment can be used with minimal modifications. Boilers are generally less sensitive to LFG trace constituents and therefore require less cleanup than other alternatives. End-use options include industrial applications such as kilns, lumber drying, oil refining, hotel heating, and cement manufacturing. These tend to be economical applications because of the continuous need and availability of the fuel.

Economics of Electricity Generation

Generally, there are three applications for LFG electricity generation: internal combustion engines, gas turbines, and fuel cells. As of 1992, there were about 61 projects that generated electricity using internal combustion (IC) engines and 24 using turbines, accounting for a total output of 344 megawatthours.[189] Today, most of the operating landfill energy recovery projects sell electricity under contract to a utility. IC engines are most economical where the supply of LFG is enough to produce 1 to 3 megawatthours. Turbines are most economical at sites with output of over 3 megawatthours. Advantages of IC engines include comparatively low capital costs (between $950 and $1,250 per kilowatt), efficiency, a high degree of standardization, and ease of transportation from one landfill site to another.[190] One of the disadvantages with IC engines is emissions. There are two types of IC engines, each having distinct

[187]M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*.
[188]S.A. Thorneloe, "Landfill Gas Utilization—Options, Benefits, and Barriers."
[189]S.A. Thorneloe, "Landfill Gas Utilization—Options, Benefits, and Barriers."
[190]M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*.

Table 30. Comparison of Costs for Typical LFG Energy Recovery Technologies
(1992 Dollars, Unless Otherwise Noted)

Technology/Use	Capital Costs (Dollars per Kilowatt)	Operating and Maintenance Costs (Dollars per Kilowatthour)
Internal Combustion Engine/Electricity Generation	900 to 1,200	0.013 to 0.020
Gas Turbine/Electricity Generation	1,000 to 1,500	0.01 to 0.015
Steam Turbine/Electricity Generation	[a]900	[a]0.001
Boiler/Direct Heat	1,000 to 1,500	0.005 to 0.018
Organic Rankine/Heat Recovery	1,000 to 1,500	0.005
Fuel Cell/Electricity Generation	[b]3,000+	NA

[a]1993 dollars.
[b]1995 dollars, using 1995 technology.
NA = not available.
Sources: T.D. Williams, "Making Landfill Gas an Asset," *Solid Waste and Power* (July/August 1992), p. 22; and C.E. Anderson, "Selecting Electrical Generating Equipment for Use with Landfill Gas," *Proceedings of the SWANA 16th Annual Landfill Gas Symposium* (Louisville, KY, March 1993).

emissions characteristics. Stoichiometric combustion engines generate high nitrous oxides (NO_x) emissions. Lean-burn engines generate lower NO_x and CO emissions, so they are better suited for applications where these emissions are a concern.

There are several economic disadvantages in using gas-fed turbines. According to Waste Management of North America, gas fed turbines typically have parasitic energy losses of 17 percent of gross output.[191] This compares to 7 percent for IC engines. Turndown[192] performance is poor compared with IC engines, and difficulties may occur when they are operated at less than a full load. Other problems can be combustion chamber melting, corrosion, and accumulation of deposits on turbine blades. Thus, IC engines are currently the most favorable option for LFG energy conversion projects and have been applied in greater numbers than any other option.

In the future, fuel cells may become attractive because of their higher energy efficiency, negligible emissions impact, and suitability for all landfill sizes, although some studies suggest that fuel cells would be more competitive in small (less than 1 megawatt) to medium (less than 3 megawatts) projects.[193] In addition, fuel cells have low labor and maintenance costs. At present, however, economic and technical disadvantages make fuel cells clearly uncompetitive with more conventional applications. These include the high capital cost of designing an LFG cleanup process that can remove the trace constituents from the LFG (fuel cells need a higher grade of LFG purification than other options), and the high cost of the fuel cell itself (about $3,000 per kilowatt using state-of-the-art technology). Because of continued advances in fuel cell technology and the possibility of more stringent future emissions requirements that may make other technologies more costly, some studies estimate that fuel cells will become competitive around the turn of this century. (A manufacturer estimates capital costs as low as $1,500 per kilowatt by 1998).[194] According to a study by the Electric Power Research Institute (EPRI), if individual fuel cell power plants were used at landfills, 6,000 megawatthours of electricity could be generated from LFG.[195] Another study prepared for the EPA suggests that the approximate total power output that could be generated from about 7,500 landfills using fuel cell energy recovery could be 4,370 megawatthours.[196]

[191]Unless otherwise noted, the technical information on gas turbines and IC engines was obtained from M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends.*

[192]Turndown refers to gas line pressure. The efficient performance of gas-fed turbines is more sensitive to gas line pressure than is the performance of internal combustion engines.

[193]G.J. Sandelli, *Demonstration of Fuel Cells To Recover Energy from Landfill Gas. Phase I Final Report: Conceptual Study,* EPA-600-R-92-007, prepared for the U.S. Environmental Protection Agency by International Fuel Cells Corporation (Washington, DC, January 1992).

[194]According to ONSI Corporation, a subsidiary of International Fuel Cell Corporation (the fuel cell production arm of United Technologies Corporation). See M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends.*

[195]W.D. Siuru, "Researchers Test Fuel Cells To Recover LFG," *World Wastes,* Vol. 38, No. 4 (April 1995), p. 8.

[196]G.J. Sandelli, *Demonstration of Fuel Cells To Recover Energy from Landfill Gas. Phase I Final Report: Conceptual Study.*

Table 31. Conditions Necessary for Cost-Competitiveness in LFG Utilization Projects

Project Developer/ Source	Technology	Administrative and Development Costs	Minimum Necessary Conditions				
			Minimum Output	Minimum Price Paid for Project Electricity	Royalties to Landfill and Emission Credits	Pipeline Length (if applicable)	Tax Incentives
Laidlaw Technology, Inc.[a] (1992)	Gas turbine	Can vary greatly, from $30,000 to $1 million per kW for a 1-MWe project	>1 MWe	At least $0.06 to $0.07 per kWh	Less than 12.5 percent	Less than 2 miles	Tax credits necessary when energy prices are low
International Fuel Cells Corporation[b] (Conceptual Study)	Fuel cell: mature technology and economies of scale	$1,500 per kW (including credits and assuming 50 percent heat recovery sold at $2.92 per million Btu)	4 x 200 kW	$0.04 per kWh	Emission offset: $1,000 per ton of NO_x and SO_x	NA	Yes
International Fuel Cells Corporation[b] (Conceptual Study)	Fuel cell: today's technology and no economies of scale	$3,000 per kW (including credits and assuming 50 percent heat recovery sold at $2.92 per million Btu	4 x 200 kW	$0.072 per kWh	Emission offset: $1,000 per ton of NO_x and SO_x	NA	Yes
NA[b,c]	Flare system	About $375 per million standard cubic feet of LFG processed per year	NA	$0.07 per kWh	None	NA	No

[a]G.R. Jansen, "The Economics of LFG Projects in the United States," presented at the Symposium on LFG/Applications and Opportunities (Melbourne, Australia, February 27, 1992).

[b]G.J. Sandelli, *Demonstration of Fuel Cells To Recover Energy from Landfill Gas. Phase I Final Report: Conceptual Study*, EPA-600-R-92-007, prepared by International Fuel Cells Corporation for the U.S. Environmental Protection Agency (Washington, DC, January 1992).

[c]G.J. Sandelli (1992) and Science Applications International Corporation, *Renewable Energy Annual 1996. Subtask II: Issues*, prepared for the Energy Information Administration under Contract No. DE-AC01-92-EI21944 (McLean, VA, September 11, 1996).

Btu = British thermal units. kWh = kilowatthours. MWe = megawatt-electric. NA = not applicable.

Economics of Using LFG as a Feedstock in Chemical Manufacturing Processes

This option involves the use of expensive cleanup, purification, and processing equipment to bring the LFG to the quality standards of alternative feedstocks, such as natural gas. Using LFG as a chemical manufacturing feedstock remains largely uneconomical as long as the price of conventional feedstocks (e.g., natural gas) remains low. Other disadvantages are high transportation costs and a need for proximity to the end user. Landfill sites have found that gas pipelines cannot exceed 1 or 2 miles to be cost-effective.[197] Potential uses for the feedstock include production of methanol and diesel fuels.

Economics of Gas Purification to Pipeline-Quality Gas

This option involves the conversion of LFG, a medium heating value gas, into high heating value gas for local gas distribution networks or, in compressed form, for vehicular fuel. In 1992, there were seven sites that upgraded LFG to pipeline-quality gas.[198] This option also remains uneconomical as long as the prices of natural gas and oil remain relatively low. Disadvantages include the need for a more thorough and expensive purification process than in some other options (but the same as in feedstock for chemical manufacturing processes and fuel cell applications), high transportation costs, and need for proximity to the end-user.

[197]S.A. Thorneloe, "Landfill Gas Utilization—Options, Benefits, and Barriers."

[198]M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends.*

Nonregulatory Government Promotion of LFG Use

The U.S. Government has an impact on the LFG industry and on the development of energy recovery projects through promotional programs and incentives. The aim of these incentives and programs is to encourage LFG utilization projects, particularly when the projects are not cost-effective due to market conditions or the use of new technology. The EPA has the most important programs regarding MSW landfills. This section provides a brief discussion of EPA's promotional programs and of other U.S. Government incentives and programs.

EPA Activities

Landfill Methane Outreach Program

The Landfill Methane Outreach Program, part of the Climate Change Action Plan, is an important Government program dealing with LFG and energy recovery. Through this program, EPA is working with MSW landfill owners / operators, States, Tribes, utilities, and other Federal agencies to promote the use of LFG as an energy resource.[199] The program has two main tasks: (1) identifying landfills with the potential to produce energy cost-effectively; and (2) overcoming the barriers to LFG energy recovery at the Federal, State, and local levels. A summary of the outreach services offered by the program appears in the box opposite. The critical barriers identified by the program are shown in Table 32.

Some of the program's outreach objectives are met through EPA's Landfill Methane Outreach "Ally" voluntary programs with State governments, utilities, and owner / operators. EPA launched these programs in five States during fall 1994; the nationwide launch took place in 1996.[200]

In the State Allies program, the EPA and a State government office sign a voluntary memorandum of understanding which sets forth the responsibilities and agreements between the parties to make the State government party a Landfill Methane Outreach State Ally.

In the Utility Allies program, utilities are encouraged to purchase electricity generated from LFG. To become a Utility Ally, a utility agrees to take advantage of the best opportunities in its service territory (or beyond) for obtaining power from LFG. In turn, EPA recognizes and publicizes the utility's efforts. EPA can also assist during evaluation and development of projects and in removing or alleviating the regulatory, information, and other barriers currently limiting development (Table 32). As in the State Ally program, utilities become allies by signing a memorandum of understanding with EPA. The National Association of Regulatory Utility Commissioners (NARUC) recognized the importance of the Utility Allies program by adopting a resolution in March 1994 "encourag[ing] and support[ing] its member commissions' and utilities' active participation in the Outreach program."[201]

The Industry Allies program encourages use of the most appropriate energy recovery technology on a site-by-site basis. Industry Allies include several types of organizations: LFG-to-energy developers, engineering consulting firms, equipment suppliers, project facilitators, project financiers, and LFG end users. Industry Ally project developers currently account for over 60 of about 100 U.S. LFG-to-energy projects.

Outreach Services of EPA's Landfill Methane Outreach Program

- A telephone assistance service for questions about collection, control, and utilization of LFG
- Provision of sample requests for proposals (RFPs) to landfill owners / operators, utilities, State regulators, and others who can use the samples in starting up LFG collection and utilization projects
- Release of case study reports on landfill successes to raise awareness of emissions reduction potential and the economics of control and conversion
- Organization of a series of State and regional workshops on landfill energy recovery opportunities
- Initiation of site visits to develop feasibility analyses of project opportunities
- Research in coordination with the U.S. Department of Energy targeting the technical barriers to energy recovery.

Sources: National Renewable Energy Laboratory, *Using Landfill Gas for Energy: Projects that Pay* (Golden, CO, May 1994); and U.S. Environmental Protection Agency, *Landfill Methane Outreach Program*, EPA-430-F-95-068A (Washington, DC, April 1995).

[199]National Renewable Energy Laboratory, *Using Landfill Gas for Energy: Projects that Pay* (Golden, CO, May 1994).
[200]U.S. Environmental Protection Agency, *Landfill Methane Outreach Program*, EPA-430-F-95-068A (Washington, DC, April 1995).
[201]Solid Waste Association of North America, web site www.swana.org (August 20, 1996).

Table 32. Critical Barriers Identified by the Landfill Methane Outreach Program and Their Solutions

Critical Barriers	Program Solutions
Lack of information and perception of high risk	Provide information to increase awareness of project opportunities and enhance understanding of environmental, energy, and economic benefits
Costly and difficult permitting and other regulatory hurdles	Work with Federal and state regulators to increase flexibility and streamline the regulations affecting development of projects
Poor market conditions: rate of return not high enough	Work with utilities and other energy purchasers to increase recognition of the environmental value of energy recovery and its energy resource benefits
Misperception of profitability based on avoided cost rates that are no longer available	Raise awareness of the benefits of energy recovery as a cost-effective approach to achieving a range of environmental and safety goals

Source: U.S. Environmental Protection Agency, *Landfill Methane Outreach Program*, EPA-430-F-95-068A (Washington, DC, April 1995).

Other EPA Activities

In addition to the outreach program, EPA offers technical assistance through its Control Technology Center. Other EPA activities include research by the Air and Energy Engineering Research Laboratory (AEERL), which provides information on energy conversion options for LFG utilization, specifically to owners/operators affected by CAA regulations.[202]

Other Federal and State Government Incentives [203]

Tax Credits and Exemptions

The most important tax credits are the Federal Production Tax Credits (PTCs), established in 1979 under Section 29 of the Tax Code. Credits are a direct offset to taxes and can only be used to offset a profit. The tax credits will apply until 2008 and are allowable for LFG extraction systems installed prior to the end of 1992. The credit was $0.94 per million Btu in 1992.

On July 9, 1996, the Senate approved a package that includes an extension for the Section 29 tax credits.[204] If signed into law, the package will extend the Section 29 deadline for a written binding contract to 6 months after the provision's enactment and extend the "placed in service" date to January 1, 1999. No extension was granted for the duration of the availability of the tax credit.

There are also State tax exemptions, such as those on LFG extraction (i.e., collection) and energy conversion facilities. Some State governments, such as California, tax these same systems.

State Price Incentives

The most important State incentives are favorable utility contracts for electricity projects, created to counter poor market conditions. A good example is California's Standard Offer No. 4, a price-favored contract that utilities were required to offer in the 1980s. Beginning in 1984, this incentive encouraged several LFG-to-energy projects, the last of which started in 1990; however, FERC rulings on above-avoided cost purchases have eliminated this and similar programs.[205] Other States that adopted incentives programs are New Jersey, New York, and Pennsylvania (now canceled), as well as Illinois, Michigan, and Wisconsin (still in place).

U.S. Department of Energy

There are three U.S. Department of Energy (DOE) programs with the objective of encouraging the development of LFG energy recovery projects:

- Research, Development, and Demonstration (RD&D) Program—Part of the Climate Change Action Plan, which targets the technical barriers to landfill methane energy recovery

[202]M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends.*

[203]Information obtained from M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends.*

[204]Solid Waste Association of North America, web site www.swana.org (August 20, 1996).

[205]Some States are planning to circumvent FERC by requiring utilities that sell at retail to buy a certain percentage of their energy from renewable supplies. As of summer 1996, no State had actually implemented such a program.

- Climate Challenge—A DOE initiative in which utilities agree to achieve greenhouse gas reductions in a way that makes sense for them
- Voluntary Reporting—A DOE program in which utilities are eligible to report methane reductions from landfill energy recovery projects.

Economic Impacts of Regulations, Programs, and Incentives

Municipal Solid Waste Landfill Regulations Under RCRA and CAA

Because of the self-implementing nature of the regulations under Subtitle D of RCRA, the stringency of State regulations affecting MSW landfills varies widely. In some cases, State regulations are much more demanding than Federal regulations (e.g., New York, New Jersey), while in other cases, States simply enforce the Federal regulations. Overall, however, increased compliance costs have forced many landfills to shut down.

The United States had 7,683 landfills in 1986 but just 5,345 in 1992. Before the 1992 list was updated, the final rule for solid waste disposal facility criteria (40 CFR Parts 257 and 258, October 9, 1991) was published. The rule allowed a facility to comply only with final cover requirements if it stopped receiving waste within 24 months. The effect of this rule was a further decline in active landfills to 3,581 in 1995.

Table 33 shows typical landfill costs, and LFG control costs in particular, before and after the 1991 version of Subtitle D of RCRA. As shown in Table 33, there was a considerable increase in landfill management costs between 1975 and 1988, followed by a smaller increase from 1988 to 1990. These increases are mostly due to the higher costs of compliance with successive versions of Subtitle D of RCRA. The weight of each item has also changed over time, as provisions have required increasingly expensive construction and postclosure care. The table also shows that the RCRA provisions that address LFG operations have contributed to increased costs in real terms, but not as a percentage share of the total cost of the project. On the other hand, the RCRA provisions that address LFG under the closure and postclosure care criteria may have contributed to increased costs both in real terms and as a percentage share of the total cost of the project.

In terms of RCRA's impact on the economics of LFG energy recovery projects, there are two main issues. First, hazardous waste disposal regulations impose a cost for disposal of LFG condensate of between $0.70 and $1.50 per gallon (compared with less than $0.01 per gallon for sewering, in the absence of regulation). In contrast, condensate disposal costs are about 80 percent lower when the LFG is flared (i.e., 1,000 gallons per day for energy recovery vs. 200 for flaring). Thus, while these regulations reduce emissions[206] (particularly for methane) they discourage the utilization of LFG and encourage flaring. Second, RCRA's requirement for

Table 33. Comparison of MSW Landfill Costs Before and After the 1991 RCRA Regulations

Cost Item	Typical Costs per Ton and Percentage Share of Total, by Year and RCRA Compliance Status					
	1975 Landfill Not in Compliance with 1976 RCRA		1988 Landfill in Compliance with 1976 RCRA		1990 Landfill in Compliance with 1991 RCRA	
	1988 Dollars per Ton	Percent of Total	1988 Dollars per Ton	Percent of Total	1988 Dollars per Ton	Percent of Total
Pre-development	0.25	5.9	0.42-1.30	3-6	1.50	7.3
Construction	0.52	12.3	2.60-4.90	15-25	5.00	24.4
Operations	3.20	75.7	4.50-8.50	30-40	8.00	39.0
Closure	0.26	6.1	0.50-1.00	3-5	1.00	4.8
Post-closure care	0.00	0.0	2.00-4.00	10-20	3.00	14.7
Unanticipated	0.00	0.0	1.00-2.50	5-15	2.00	9.8
Total	**4.23**	**100.0**	**11.02-22.20**	**100.0**	**20.50**	**100.0**

Source: R.T. Glebs, "Subtitle D: How Will it Affect Landfills?" *Waste Alternatives* (Summer 1988).

[206]Assuming that the combustion efficiencies of flaring and energy recovery are similar, the CO_2 emissions are comparable. Therefore, if the LFG were redirected through an energy conversion combustor/generator rather than flared, no new CO_2 emissions would be created.

CAA compliance raised costs by requiring expensive emission prevention systems or applying penalties.

The cost impact of the 1996 New Source Performance Standards and Emissions Guidelines under the CAA will be minimal. Only about 280 landfills are affected by the regulations. Of the 900 new landfills projected to open during the next 5 years, approximately 45 will be subject to the regulation. By requiring more extensive (and expensive) LFG control, the rule may encourage some landfills to explore LFG energy recovery options. However, because the rule increases the costs of both flaring and energy recovery options, most owners/ operators will likely continue to choose flaring.

State and Local Environmental Regulations

The reach of State and local environmental regulations is expanding at an increasing rate. According to industry sources, the costs for LFG energy recovery projects of complying with all pertinent regulations are escalating faster than the inflation rate and original financial assumptions.[207] An example is a penalty for the CO_2 content in emissions from engines in California, which applies specially to LFG energy conversion projects that use IC engines. The penalty can add as much as 1.5 cents per kilowatthour to operating expenses.

Federal Energy Regulatory Commission

The FERC's rejection of the component of California's Biennial Resource Plan Update that restricted bidding for wholesale power to QFs means that States may not assign a preference to bidding for LFG-generated energy under PURPA. States also may not assign externality benefits to particular technologies.

EPA, DOE, and Other Federal Incentives

Although the EPA's Landfill Methane Outreach Program has identified the most important barriers to energy recovery projects, its solutions so far have been mostly cosmetic. While its role of providing reliable information to the marketplace is necessary, the solution to the main identified barrier is well beyond its capabilities; no amount of recognition of the environmental value of energy recovery is likely to have a significant impact on LFG energy recovery project development until rates of return are comparable to those of fossil fuel alternatives.

DOE and EPA research programs have not, so far, resulted in significant commercial project developments. Critics of technology demonstration programs argue that they amount to ineffectual government industrial policy that misallocates public resources. To others, however, these projects are essential to maintain private sector interest in emerging technologies, which may result in commercially viable projects by the turn of the century.

For the purpose of LFG energy recovery project development, the most significant positive impact is that of the Federal production tax credits for LFG extraction systems of $0.94 per million Btu in 1992.

Impact of State Incentives

State incentives in the form of favorable utility contracts for electricity projects have contributed to the development of LFG energy recovery projects more than any other government incentive or program. The historical record indicates that these incentives are essential for some projects, which would otherwise be forced to shut down if the pricing structure reverts to the avoided-cost basis. It is no coincidence that the seven States that have offered or are currently offering incentives are also the top seven in terms of number of projects and account for about three-quarters of all projects in the United States.[208]

[207]F.P. Wong, *Alternative Energy and Regulatory Policy: Till Death Do We Part* (Commerce, CA: Pacific Energy, March 1992).

[208]M. Doorn, J. Pacey, and D. Augenstein, *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends.*